Scale Interactions within the Madden-Julian Oscillation

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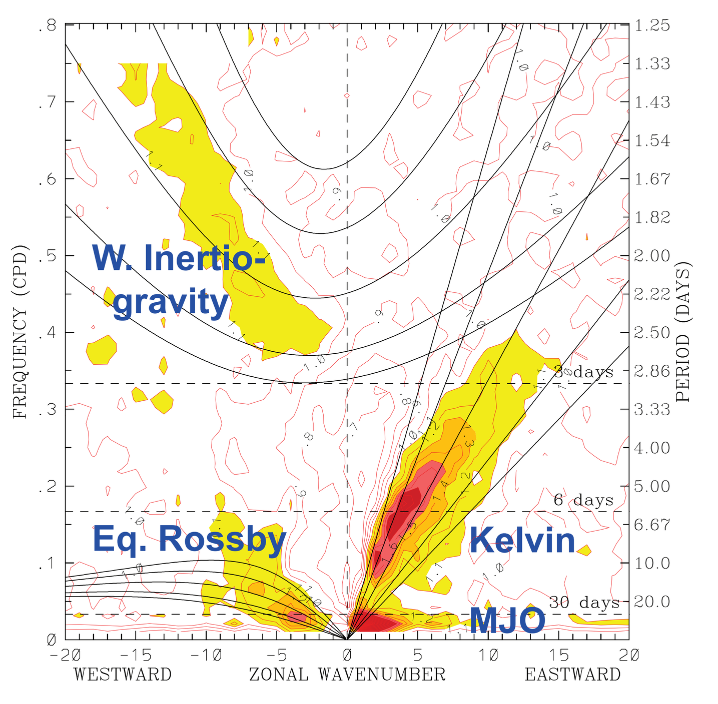
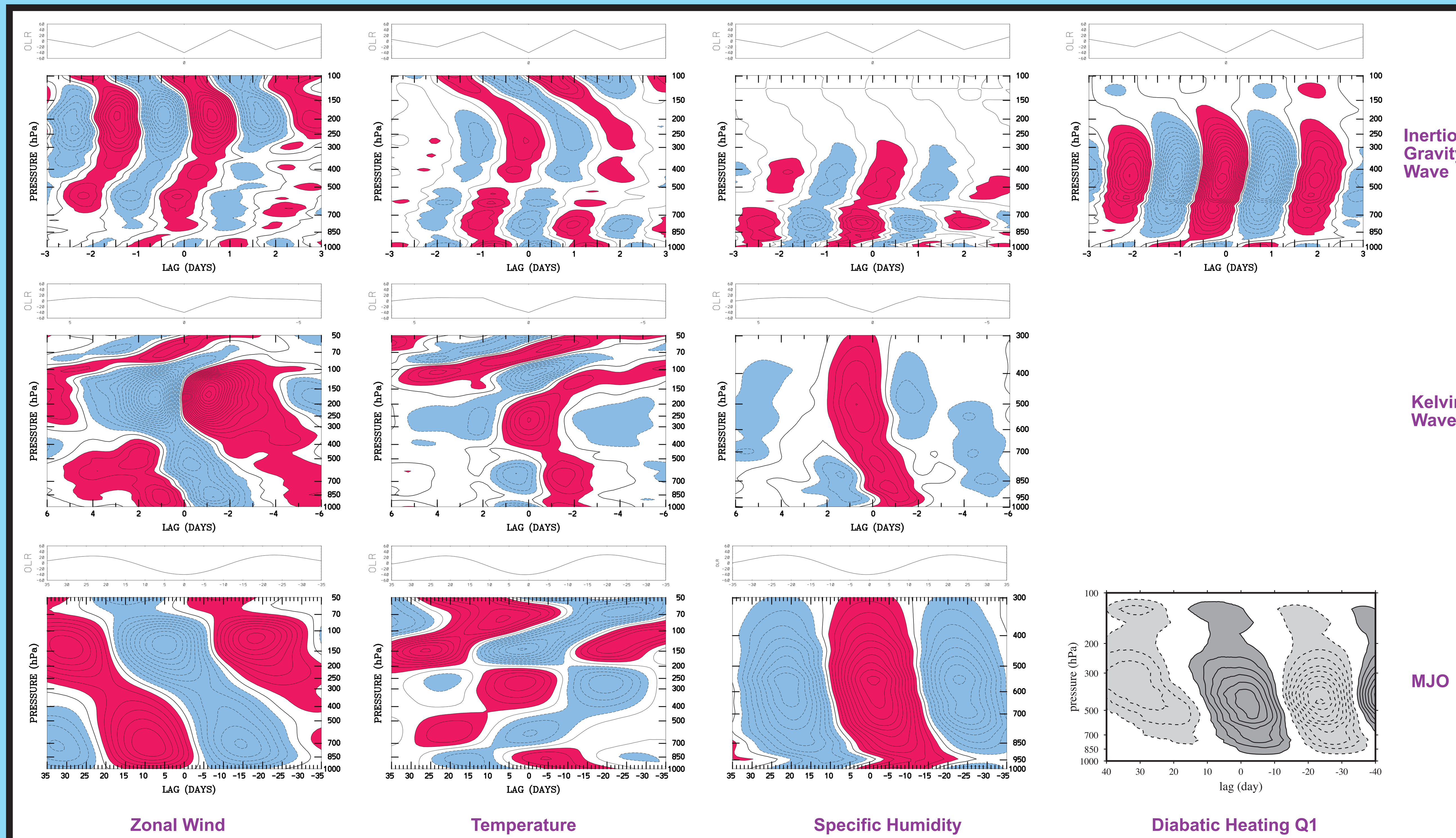
Introduction

This poster summarizes some key findings of a series of studies by the author and colleagues over the past few years investigating the structure of convectively coupled equatorial disturbances. This work has been funded in part by by the CLIVAR Program of NOAA's Climate Program Office under the project title “Scale Interactions between Convection, Equatorial Waves, and the Tropical Pacific Ocean-Atmosphere System.”

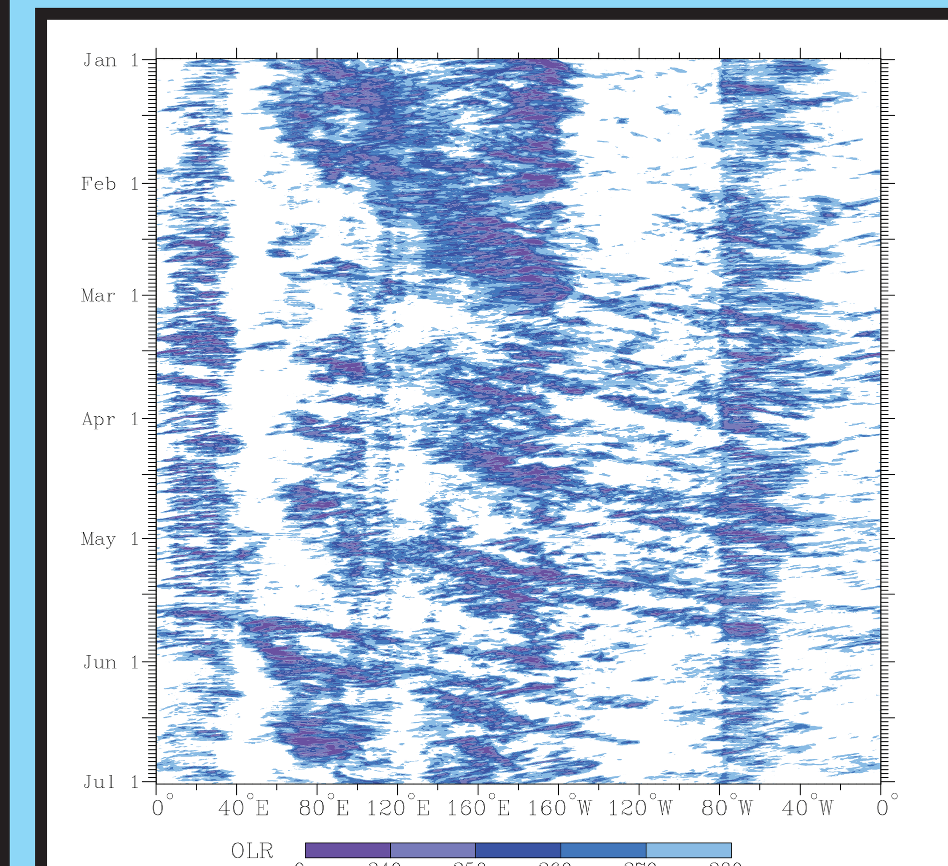
Convectively coupled waves are isolated through space-time filtering of Outgoing Longwave Radiation (OLR) using the methodology of Wheeler and Kiladis (1999). Below is a space-time spectrum of tropical OLR for 1979-2004. Spectral peaks associated with Kelvin, equatorial Rossby, and westward inertio-gravity waves show up clearly, as does the MJO. An inverse transform using coefficients surrounding these space-time peaks produces a filtered OLR data set for a given disturbance. Dynamical fields can then be regressed against the filtered OLR to produce ”composite” structures for each wave type.

Here we compare the dynamical structure and cloudiness evolution of three modes: the westward inertio-gravity wave, the Kelvin wave, and the MJO. Results indicate a certain level of “self-similarity” amongst the waves regardless of scale, present even down to the mesoscale.

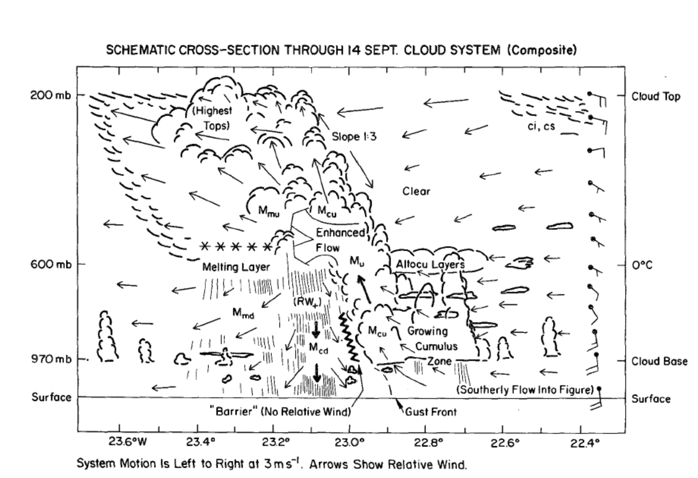




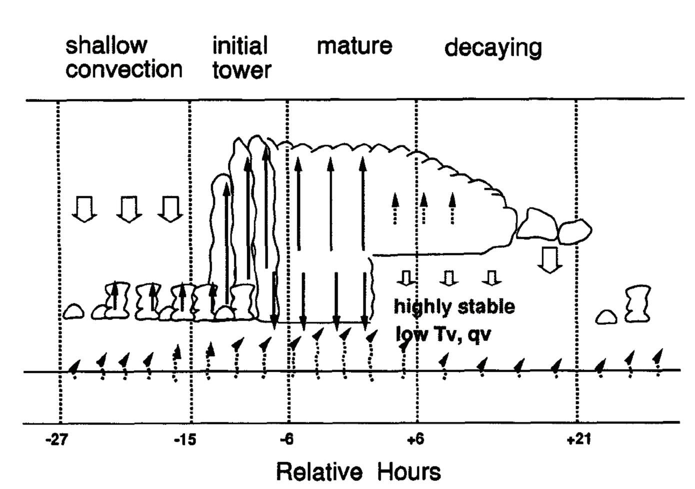
To the left are panels of regressed zonal wind, temperature, specific humidity, and diabatic heating (Q1) for westward inertio-gravity and Kelvin waves, along with the MJO. These were obtained by projecting a given parameter in tropical island radiosonde data onto appropriately filtered OLR at the nearest grid point to the sonde location, producing composites of time-height evolutions. Convectively coupled disturbances universally exhibit strong vertical tilts in their wind, temperature, moisture, vertical velocity and diabatic heating fields. In general these disturbances display a warm lower troposphere ahead of the wave, with cooling behind, and a warm mid-troposphere within the convective region. Low level moisture and thus CAPE and moist static energy is high ahead of the waves, and drying occurs first at low levels while it is still moist aloft behind the wave. Low level diabatic heating precedes deep convective heating, followed by a signal of upper tropospheric heating over cooling. This is consistent with the typical evolution of cloudiness within the waves as shown below.



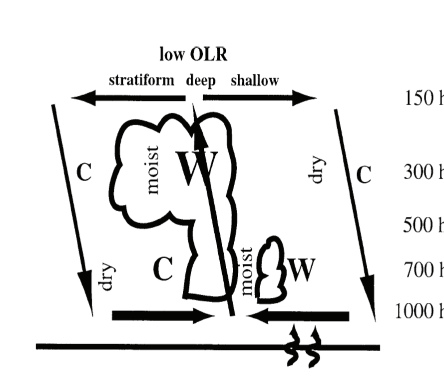
The Hovmueller diagram of equatorial brightness temperature above shows a sequence starting with the MJO which then decays while a series of Kelvin waves continues to propagate eastward at 15 m/s for several months. Interestingly, the Kelvin waves often propagate completely around the globe, and appear largely uninhibited by barriers such as the Andes. It is obvious that the MJO is comprised of smaller scale disturbances, some of which can be identified as Kelvin and inertio-gravity waves, and these in turn are comprised of a broad spectrum of mesoscale features not organized into "waves". This suggests a dominance of both upscale and downscale interactions in the organization of tropical convection.



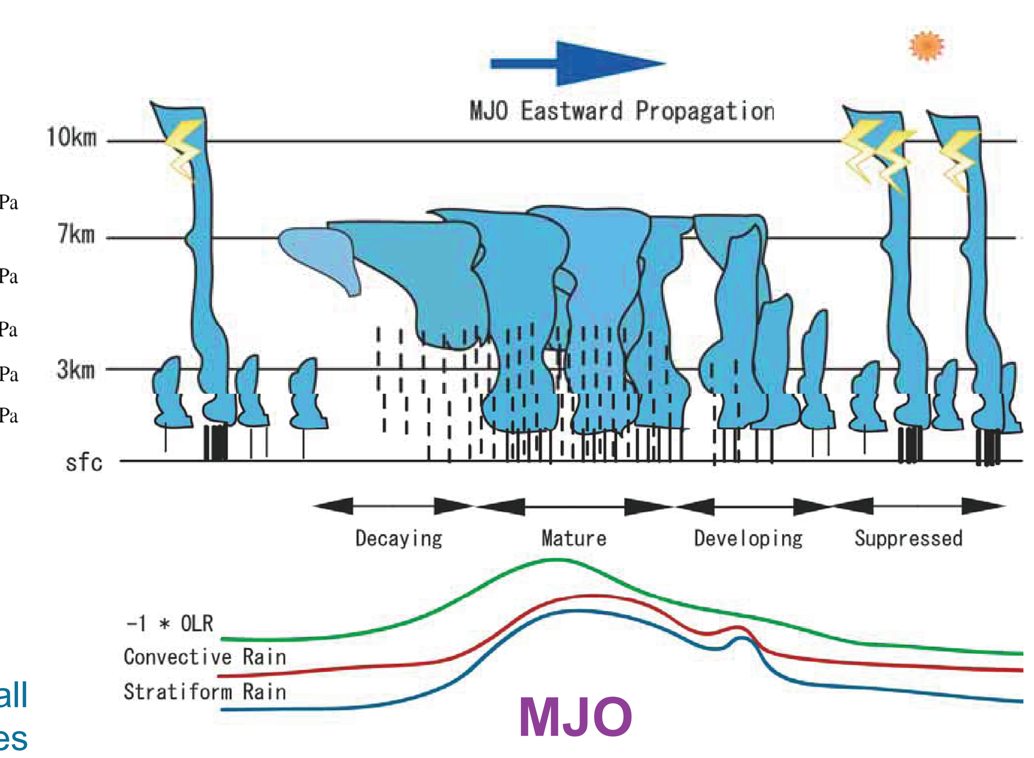
GATE Squall Line



W. Inertio-Gravity Wave



Kelvin Wave



MJO

Above and to the right are plots of the horizontal structure of cloud morphology from various studies of tropical squall lines during the GATE field experiment, Westward Inertio-gravity (2-day) waves from TOGA COARE, Kelvin waves during the TEPPS experiment, and the MJO. These pictures are based on ground observations and also satellite data, except for the case of the GATE study.

For all of the waves studied from the mesoscale on up to the MJO, cloudiness evolves from shallow convection along the leading edge, which then develops into deep convection, evolving into stratiform precipitation along the trailing edge. This morphological evolution is even mirrored by the development of an individual cumulus cell in the tropics, which is controlled primarily by microphysics and mesoscale dynamics. This remarkable scale invariance is present all the way up to the planetary scale in the MJO. While this observation appears to indicate that dynamics of large scale waves determine the distribution of of cloud type populations within them, the mechanism of this systematic modulation is not well understood. Presumably, there are also crucial upscale energy transports occurring as a result of the cloud populations. However, observations suggest that this can be enabled by a wide variety of embedded smaller scale disturbances, since for example two different MJOs can be composed of a completely different spectrum of waves.

Discussion

* There is a surprising level of scale invariance in the vertical dynamical structures and cloud evolution within tropical waves, from the mesoscale all the way up to the planetary scale MJO.

* The horizontal structures of the waves (not shown here) corresponding to the space-time spectra of tropical cloudiness show a remarkable similarity to their theoretical structures as derived by Matsuno (1966).

* The vertical structures of the temperature and moisture fields of the waves are consistent with their cloudiness evolution. A warm, moist boundary layer ahead of the wave leads to shallow convection and then to congestus clouds, which moisten the mid-troposphere. This creates an environment favorable for the development of deep convection, which rapidly lofts moisture into the middle and upper troposphere. Mid- to upper-tropospheric temperature peaks within deep convection, as a response to latent heating. At the trailing edge of the wave a predominance of stratiform precipitation dominates, yielding a warm, moist upper troposphere and a relatively dry, cool lower troposphere.

* The vertical structure of the latent heating indicates that two “vertical modes” can account for most of the structure, with the first mode representing deep convection and the second shallow and stratiform precipitation (Haertel and Kiladis 2004; Kiladis et al. 2005; 2009). This aspect of self-similarity is also present across a wide range of scales.

References:

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